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Fire Management Notes

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Fire
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Notes

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Contents

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U.S. Department of Agriculture

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Cooperative Fire Protection

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General Manager

Cover: Bulldozer operators risk their lives carving out firebreaks to combat fires.

Ignition of Grass Fuels by Cigarettes

Clive M. Countryman

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Discarded cigarettes are often cited as the cause of wildland fires, especially when no other causative agent is readily apparent. But the evidence is by no means conclusive that cigarettes as frequently cause fires as is widely assumed. Informal tests by various fire agencies have indicated that the ignition of surface fuels, such as dead grass or pine needles, seldom occurs when a cigarette is dropped on the fuel. Usually some manipulation of the fuel or cigarette is necessary to achieve ignition—an action unlikely with a casually discarded burning cigarette.

This paper reports the results of a study undertaken to determine the conditions under which cigarettes start fires in dead grass fuels. Although the study was not completed over the range of conditions planned, sufficient information was obtained to provide some insight into the parameters controlling the ignition of grass fuels by cigarettes.

Study Development

Exploratory Tests. All ignition tests were conducted in a chamber in which air temperature, relative humidity, windspeed, and simulated solar radiation can be controlled. Exploratory tests were first conducted using samples of wild oats (*Avena fatua*) and cheat grass (*Bromus tectorum* L.). These samples were cut from natural stands of dead grass by forcing a sharpened 6-inch-in-diameter steel tube through the grass and 2 or 3 inches into the mineral soil. The soil from around the tube was then removed and the sample cut off at the bottom of the tube. A metal band was used to hold the soil and litter in place when the sample was removed from the cutting tube. The samples were stored in the laboratory at room temperature and humidity for at least 2 weeks before ignition tests were made.

In the test chamber the samples were placed in a recess in the chamber floor so that the litter layer was level with the floor. The samples were then conditioned for 2 hours at the air temperature and relative humidity selected for the tests. A windspeed of 3 mi/h was used in all of these exploratory tests. Cigarettes were allowed to burn to a 2-inch length and then were dropped on the fuel sample.

Ignition—either glowing or flaming—was not attained in any of these first tests. Individual stalks of grass in contact with the cigarette would char, sometimes glow briefly and burn through, but all combustion activity would cease as soon as the cigarette burned out.

The failure to obtain ignition of the standing grass fuel appeared to be associated with the characteristics of the grass fuel bed. The standing material had a very loose, open arrangement, but was dense enough to prevent the cigarettes from reaching the litter layer. As a result, the cigarettes were supported above the litter by only a few grass stalks. Cigarettes also burn slowly, and consequently only one or two grass stalks at any given time were exposed to temperatures high enough to cause ignition. Air circulation through the loosely arranged fuel bed was good, facilitating rapid removal of heat and combustible gases. As a result of the slow rate of heat production from the cigarettes, the small quantity of fuel heated, and the large heat losses, the probability of ignition of standing grass fuel by cigarettes appears to be low.

The litter layer under the grass, however, is fairly compact with a relatively smooth surface. By deliberately placing cigarettes on this layer, sustained glowing combustion of the fuel was obtained. Thus, cigarettes reaching the litter layer appear much more likely to start a fire than those supported above the litter by the grass. The characteristics and condition of the litter layer are, therefore, of major importance in determining the propensity for cigarettes to start fires. Consequently, further tests in the study were focused first on the litter fuel.

Procedures. To provide uniform material for ignition tests, the litter was simulated by chopping grass in a Wiley Mill with the screens re-

moved. The chopped material was then separated into three size classes—fine, medium, and coarse—with a South Dakota seed blower. This method separated the fuel by density as well as size. The fine fuel resembled a coarse powder, with most grass bits less than 0.1 inch long, and a few thin pieces up to 0.5 inch long. The medium-size class consisted chiefly of grass splinters 0.1 to 0.2 inch long and some thin pieces up to 0.75 inch long. The coarse fuel was made up mostly of larger grass splinters and thin whole grass pieces 0.75 to 1.50 inches long. This fuel class also contained some small but dense material.

Metal containers were used to hold the fuel during the ignition tests. These containers were 3 inches in diameter and either 0.25 or 0.50 inch deep. The bottoms of the containers were lined with asbestos paper to provide insulation between the fuel and the metal. The fuel containers were fitted into a wooden plate with the fuel surface level with the plate surface, and the plate was placed in a recess in the test chamber so that its surface was level with the chamber floor.

Most of the tests were made with a windspeed of 3 mi/h and an air temperature of 80° F. Relative humidity was varied from 14 to 85 percent to give different fuel moistures. The fuel beds were conditioned for 2 hours in the chamber before ignition tests were made to allow the fuel to reach air temperature and to approach equilibrium moisture. The fuel beds were conditioned in groups of two to four—one fuel bed was reserved in each test run for fuel moisture determination by the oven-drying method.

The cigarettes were allowed to burn to a 2-inch length before being placed on the fuel beds. Three burning tip orientations were used in many of the tests—facing directly into the wind (0°), at right angles to the wind direction (90°), and facing away from the wind (180°). When more than one orientation was used, the tests were made simultaneously on different fuel beds. Each test was continued until all combustion activity stopped.

Results

Ignition tests were completed for cheat grass at an air temperature of 80° F and windspeed of 3 mi/h with fuel depths of 0.25 and 0.50 inch. Fuel moistures ranged from 1.9 to 14.7 percent. The primary aim of this series of tests was to establish the fuel moisture at which the fuel was not likely to ignite.

Deciding whether ignition occurred was subjective because the fuel in contact with the cigarette charred or glowed in all of the tests. Tests in which the combustion of the fuel ceased soon after the cigarette had burned out and did not spread appreciably away from the cigarette were considered nonignitions. Tests in which the fuel continued to burn after the cigarette had burned out, but in which the burned area did not approach the edge of the fuel bed before combustion stopped were classified as marginal ignitions. Only tests in which the fuel burned to the edge of the fuel bed at one or more points were considered as positive ignitions. The results of the ignition tests are summarized in tables 1 and 2.

The fine fuel in the 0.25-inch depth fuel beds ignited readily with fuel moistures up to 10 percent at the 3 mi/h windspeed (table 1). At these moistures nearly all of the fuel was consumed. Above 13 percent moisture, however, the ignition tended to become marginal, suggesting that fuel moistures in the order of 14 or 15 percent would probably prevent ignition. With a windspeed of 1.6 mi/h, ignition was obtained at 5-percent fuel moisture for both the 0° and 90° tip orientations, but the burn pattern was irregular and not all of the fuel was consumed. At 9.9 percent moisture, the fuel burned for only about 0.25 inch away from the cigarette with the 0° tip orientation, and about half this distance with the burning tip at 90° to the wind direction.

The medium fuel gave much more erratic results than the fine fuel. Positive ignitions were obtained at moistures below 4 percent for both the 0° and 180° tip orientations. Above this moisture the

Table 1—*Ignition of grass fuel by cigarettes (0.25-inch fuel depth)*

Fuel moisture	Wind speed	Tip orientation	Ignition class[1]
Percent	*Mi/h*	*Degrees into wind*	
Fine Fuel			
1.8	3.0	0	I
4.7	3.0	0	I
6.3	3.0	0	I
6.4	3.0	0	I
8.4	3.0	0	I
8.7	3.0	0	I
9.4	3.0	0	I
9.6	3.0	0	I
10.0	3.0	0	I
13.4	3.0	0	I
13.5	3.0	0	M
13.5	3.0	90	M
13.5	3.0	180	N
5.0	1.6	0	I
5.0	1.6	90	I
9.9	1.6	0	N
9.9	1.6	90	N
Medium fuel			
3.7	3.0	0	I
3.9	3.0	0	M
4.8	3.0	0	N
5.7	3.0	0	N
6.2	3.0	0	N
6.6	3.0	0	M
6.6	3.0	0	M
8.3	3.0	0	N
9.4	3.0	0	N
3.7	3.0	90	M
3.9	3.0	90	M
4.8	3.0	90	N
6.6	3.0	90	N
7.4	3.0	90	N
3.7	3.0	180	I
3.9	3.0	180	I
4.8	3.0	180	M
6.6	3.0	180	M
Coarse fuel			
1.9	3.0	0	N
6.7	3.0	0	N
10.7	3.0	0	N

[1] I = Ignition; M = Marginal; N = Nonignition

ignition of the fuel was marginal or did not ignite at all. Only marginal ignition occurred with the 90° tip orientation at moistures below 4 percent; no ignitions were obtained with moisture 4.8 percent and above. The coarse fuel showed little inclination to ignite despite fuel moisture as low as 1.9 percent.

The fine fuel in the 0.50-inch depth fuel beds ignited quickly for all three burning tip orientations up to 11.8 percent fuel moisture (table 2).

Results with the medium fuel in the 0.50-inch depth fuel beds were less erratic than with the 0.25-inch depth beds. With the 0° cigarette tip orientation, ignitions were obtained with fuel moistures up to 13.6 percent, and marginal ignition at 14.7 percent. The fuel did not ignite at 14.7 percent moisture when the burning tip was at 90° to the wind direction, and only marginal ignition was obtained at lower fuel moistures. With the 180° tip orientation, ignition occurred at 3.9 percent fuel moisture and failed at 14.7 percent. Only marginal ignition occurred at intermediate moistures. No ignitions were obtained in the coarse fuel.

Discussion. The ignition tests were not completed over the wide range of fuel and environmental conditions originally planned. Consequently, definitive relationships could not be established from the data obtained. However, the results indicate that fineness of the

Table 2—*Ignition of grass fuel by cigarettes (0.50-inch fuel depth)*

Fuel moisture	Wind speed	Tip orientation	Ignition class[1]
Percent	*Mi/h*	*Degrees into wind*	
Fine Fuel			
3.7	3.0	0	I
4.0	3.0	0	I
5.8	3.0	0	I
9.8	3.0	0	I
10.6	3.0	0	I
11.8	3.0	0	I
3.7	3.0	90	I
4.0	3.0	90	I
5.8	3.0	90	I
9.8	3.0	90	I
10.6	3.0	90	I
11.8	3.0	90	I
3.7	3.0	180	I
4.0	3.0	180	I
5.8	3.0	180	I
9.8	3.0	180	I
10.6	3.0	180	I
11.8	3.0	180	I
Medium fuel			
3.9	3.0	0	I
4.0	3.0	0	I
6.6	3.0	0	I
13.6	3.0	0	I
14.7	3.0	0	M
3.9	3.0	90	M
4.0	3.0	90	M
6.6	3.0	90	M
13.6	3.0	90	M
14.7	3.0	90	N
3.9	3.0	180	I
4.0	3.0	180	M
6.6	3.0	180	M
13.6	3.0	180	M
14.7	3.0	180	N
Coarse fuel			
4.9	3.0	0	N
5.4	3.0	0	N
4.9	3.0	90	N
5.4	3.0	90	N
4.9	3.0	180	N
5.4	3.0	180	N

[1] I = Ignition; M = Marginal; N = Nonignition

fuel, fuel bed depth, orientation of the burning cigarette tip with wind direction, and windspeed all influence the probability of ignition of grass fuels by cigarettes. In general, ignition was obtained more readily with increasing fineness of the fuel, fuel bed depth, and windspeed, and with decreasing fuel moisture. Cigarettes with the burning tip facing into the wind also ignited the fuel more readily than with other tip orientations.

Cigarettes appear to be marginal causative agents because of the relatively low temperature of the surface of the burning cigarette and their slow rate of heat release. Consequently, factors affecting the amount of heat needed to ignite the fuel, the efficiency of heat transfer, and the heat losses become relatively more important with cigarettes than would be the case with a more effective type of firestarter. Fine fuels can be heated quickly to ignition temperature because of their large surface area to volume ratio and thus ignite more readily than do coarser fuels. More of the fuel particles were in intimate contact with the cigarettes on the fine fuel beds than with the coarser fuel, further enhancing the probability of ignition of the fine fuel. The greater probability of sustained ignition in the deeper fuel is probably due to the larger amount of fuel initially ignited by the cigarette and also to less heat loss through the bottom of the fuel

bed. The fuel beds burned to their full depth in all tests in which positive or marginal ignitions were obtained.

The effect of tip orientation on ignition probability appeared to be associated with the wind. Cigarettes with the burning tip facing into the wind tended to burn more rapidly than with other orientations, thus providing a greater rate of heat release. It is probable, however, that there is an optimum windspeed for ignition because increasing air flow also results in greater heat loss, and at some level of windspeed the loss may exceed the gain from more rapid burning.

In the tests listed in tables 1 and 2 the fuel burned by glowing combustion—no flaming occurred. To determine if higher fuel temperature could induce flaming, a few tests were made with fine and medium fuels using simulated solar radiation to raise the fuel temperature to 136° F. Air temperature was 86° F and the windspeed 2 mi/h. The relative humidity for these tests was 14 percent and the fuel moisture less than 2 percent. All of the fuel in these tests was consumed, but no flaming occurred.

Some tests were also made using lighted paper matches on the fuel beds. The fine and medium fuels flamed as long as the matches burned and then reverted to glowing combustion. Some of the tests with matches on the coarse fuel did produce flaming combustion that continued until most of the fuel had burned. Lack of sufficient oxygen in the compact fine and medium fuels may be the primary reason that these fuels do not flame.

Additional Tests. To gain some insight into the process by which cigarettes induce flaming ignition of grass fuels, two exploratory tests were conducted. In these tests, about two-thirds of the surface of 0.50-inch depth fuel beds of fine fuel were covered with a layer of unprocessed grass and a small amount of the coarse processed fuel. The fuel beds were conditioned for 2 hours in the test chamber at 104° F and 8 percent relative humidity. Fuel moisture was not obtained. A windspeed of 3 mi/h was used in the tests, but obstructions were placed ahead of the fuel beds to give the more erratic air flow characteristic of natural conditions in the open. Lighted cigarettes were placed on the uncovered part of the fuel beds. In one test the overlayer of fuel burst into flame after nearly all of the fine fuel had been consumed by glowing combustion. In the other, the overlayer smoked and charred but did not flame. A larger fuel bed may have induced flaming, however.

The completed tests indicate that the ignition of grass into an active fire is probably a two-stage process. A cigarette falling into natural grass and supported above the litter is unlikely to start a fire. If the cigarette reaches the litter, however, it can initiate glowing combustion, but flaming of this fuel is unlikely. Under some fuel arrangements and conditions—not yet clearly defined—the glowing combustion in the litter can cause flaming of the coarse and loosely arranged fuel above the litter. Once ignited, the glowing combustion of the litter tends to be persistent, especially at low fuel moistures. The 3-inch-in-diameter fuel beds burned for 8 to 30 minutes. Consequently, the fire in the litter can spread slowly to an area where flaming combustion can be established. Active fires in grass can thus occur long after the cigarette causative agent has burned out.

Conclusion. Fire occurrence statistics indicate that many wildland fires originate along roads and trails. Because these areas are those in which cigarettes are likely to be discarded, the fire starts are often attributed to cigarettes. Such areas are also the places where grass is likely to be ground by vehicle and foot traffic into the fine material susceptible to ignition by cigarettes. Removal of the fine material—for example, by blowing it beyond the zone where cigarettes are likely to fall—could be a means of substantially reducing the number of fires starting along roads and trails. ■

FEES: Finetuning Fire Management Economic Analysis

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Resource managers have generally been given great latitude in determining their program composition, but they are faced with ever-tightening budgets. This has forced them to closely consider economic efficiency. Fire managers are not exceptions.

In the face of increasing fire protection expenditures with no discernible increase in benefits, the U.S. Senate Appropriations Committee in 1978 recommended that the U.S. Department of Agriculture, Forest Service conduct a cost-benefit analysis of both presuppression and suppression activities and base its fiscal year 1980 budget request on its findings.

Responding to the Appropriation Committee's recommendation the Forest Service studied fire management programs on six widely dispersed National Forests in 1979 (*1*). Economic efficiency of two program components—initial attack force and aviation operations—were analyzed with marginal analysis. The criterion for economic efficiency was the minimization of the total fire program cost plus net value change (C + NVC) in resource outputs and structures due to fire. Four budget levels and 3 years of varying fire severity were evaluated for each of the six forests. The results were surprisingly similar for all forests: as budgets for initial attack force and aviation operations increased, simulated total suppression costs decreased. The decrease contrasted with the historical rise in total suppression costs that had accompanied increasing presuppression budgets.

In 1980, the Forest Service developed additional methodology and analyzed the economic efficiency of the fire management programs on 41 separate National forests with similar results. Also this study found that effects of fire on wildlife habitat and watershed could be beneficial in selected areas and in turn would substantially change those resource outputs after fire.

Subsequently, a procedure for analyzing fire management programs that incorporated many points from both of these analyses was developed and published in the "Fire Management Analysis and Planning Handbook (draft)" (*3*). It prescribes a four-level fire management analysis process to aid managers in integrating fire management considerations into land management planning.

The analysis process could be improved by a procedure complementing the present fire management analysis process for first-level (broad geographic) analysis that would limit the number of fire program alternatives that would need to be examined at the Forest level. This would significantly reduce the effort required in the second-level analysis. Developing additional analysis procedures to determine the most cost-efficient fire management funding level and allocation has been assigned to the fire management planning and economics research work unit of the Pacific Southwest Forest and Range Experiment Station at Riverside, Calif. The procedures being developed at Riverside could form an integral part of the first stages of land management planning, in which the issues, concerns, and capabilities of the area under evaluation are considered in selecting broad-scale program alternatives.

Fire Economics Evaluation System

The research unit at Riverside is developing an integrated system, called the Fire Economics Evaluation System (FEES), to produce two types of information for each fire management situation evaluated: cost plus net value change, including risk; and change in resource outputs. FEES, which is not yet operational, but is being developed for future application, will have these attributes:

- The criterion of economic efficiency will be minimizing the C + NVC.
- Risk will be represented by probability distributions of the range of possible consequences of a fire program option due to the inherent variability of fire occurrence and behavior in an area of given physical characteristics.

- The effects of fire on physical resource outputs will be measured by comparing the amount and timing of the resource outputs expected without fires with those expected after fires occur.
- The analysis procedure or simulation model will incorporate five major fire management activities—fuel treatment, prevention, detection, initial action, and extended action suppression—and will analyze trade-offs between them. Priority in system development will be given to fuel treatment, initial action, and extended action.
- The model structure will be applicable nationwide on all wildlands to aid fire managers at the State level who are conducting cost-benefit analyses of their programs, as well as Federal agencies.
- A societal viewpoint will be used. It looks at costs and benefits to society in general when determining program costs and fire effects, rather than the perspective of a single landowner.

Application of FEES

Once it is operational, FEES will be tested over a broad range of stylized "fire management situations" distinguished from each other on the basis of several dimensions that will significantly influence the output. The dimensions, which have been tentatively identified, include land management objectives, natural resources, topography, access, weather, fire occurrence, and fuel profiles.

The model will calculate an expected C + NVC value (a) for a given program dollar level (A) and fire management mix (FMM_2), which is a combination of firefighting resources (see fig. 1). For each fire management mix (FMM_1 . . . FMM_N), curves of expected C + NVC values would result from varying the program dollar level by increments. The distribution of risk estimates about each curve would be calculated as the input and output parameters of each case are expressed as probability distributions. Both fire management mix and program dollar level will have to be systematically varied because both influence fire program performance.

The primary output of changing levels and mix will be the envelope of the C + NVC curve across the relevant range of program levels (dashed curve in fig. 1). If realistic mixes are evaluated, the fire management mix (FMM_2) and program dollar level (A) that minimize C + NVC could be identified. Likewise, the impact on the C + NVC (b) from a decision based upon other than economic factors, such as a budget reduction (from program dollar level A to B), could be estimated. If the fire management mix and program dollar level are changed from the combination that

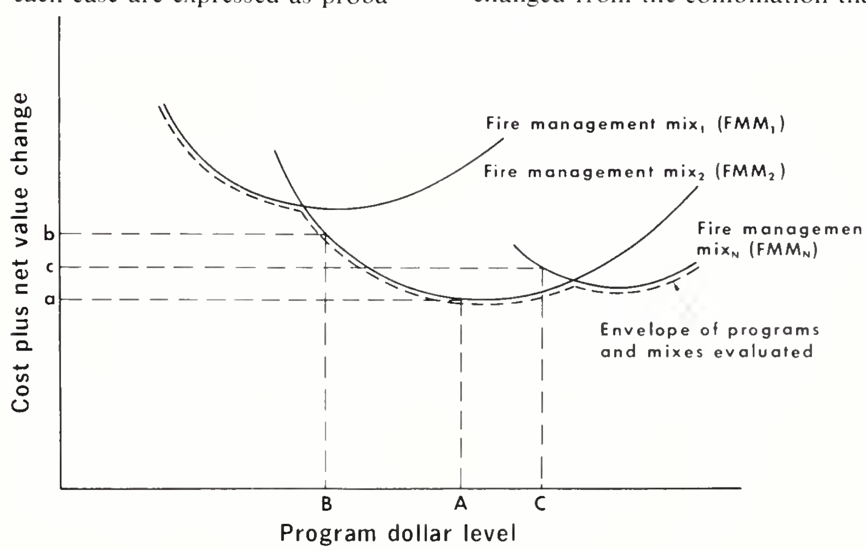

Figure 1—*The FEES model calculates an expected total fire program cost plus net value change for a given program dollar level and fire management mix.*

maximizes economic efficiency—for example, because of the desire to achieve certain environmental effects (to level C)—the resulting impact on C + NVC (c) could also be determined.

Operational Use of FEES

Operational access to FEES has not yet been determined. One alternative is to provide the fire program planner a computer software package. A second alternative is to collect data and operate FEES at a central location for a wide range of fire management situations and fire program options. Centralized processing would not mean centralized decisions, however. Weights on the decision parameters and results would still have to be applied locally.

Perhaps the most useful output format could be a display—a "FEES Guidebook" containing pages similar to figure 2. The first category of model output, cost plus net value change (expected value), will provide the economic efficiency information. The fire management mix (FMM_I . . . FMM_N) and program dollar level (PL_I . . . PL_N) that yield the lowest expected value C + NVC, and thus the highest economic efficiency, can be identified by the manager. Each FMM and PL can also be evaluated for different suppression strategies (SS_I . . . SS_N) as well.

The second output, cumulative probability distribution, is an expression of risk inherent in each fire management program option evaluated. It answers the question: What is the probability that the C + NVC is, say, one-quarter the expected value (0.25 EV) or twice the expected value (2.00 EV)? This distribution display permits the decisionmaker to appreciate the risk associated with the decision and weigh its importance relative to economic efficiency and resource output effects.

The third output, risk percent, is the statistical 90th percentile risk percent.

The fourth output category is the change in resource output between fire and no-fire resource output time streams. These effects on resources provide insights into the fire's impacts upon various wildland user groups, for example, the timber industry and recreationists.

Outlook

The Fire Economic Evaluation System is but one step in a multilevel process that provides inputs on fire economics for improving the land management planning process.

<table>
<tr><th colspan="3">Fire Management Program Option</th><th colspan="13">Cost-Plus-Net Value Change</th><th colspan="9" rowspan="2">Change in Resource Outputs</th></tr>
<tr><th colspan="3"></th><th colspan="4">Expected Value</th><th colspan="8">Cumulative Probability Distribution</th><th>Risk Percent</th></tr>
<tr><td>PRESUPPRESSION PROGRAM LEVEL</td><td>PRESUPPRESSION FIRE MANAGEMENT MIX</td><td>ESCAPED FIRE SUPPRESSION MIX</td><td>PRESUPPRESSION COST</td><td>SUPPRESSION COST</td><td>NET VALUE CHANGE</td><td>TOTAL</td><td>≤ .25EV</td><td>≤ .50EV</td><td>≤ .75EV</td><td>≤ 1.00EV</td><td>≤ 1.25EV</td><td>≤ 1.50EV</td><td>≤ 1.75EV</td><td>≤ 2.00EV</td><td></td><td>TIMBER—CF*</td><td>RANGE—AUM</td><td>WATER—AF</td><td>RECREATION—RVD</td><td>WILDLIFE—RVD</td><td>FISHERIES—SPORT—RVD</td><td>FISHERIES—COMMERCIAL—LB</td><td>IMPROVEMENTS—PUBLIC—UNITS</td><td>IMPROVEMENTS—PRIVATE—UNITS</td></tr>
<tr><td colspan="3">($/MILLION ACRES)</td><td colspan="4">(THOUSAND DOLLARS)</td><td colspan="8">(PROBABILITY)</td><td>(PERCENT)</td><td colspan="9"></td></tr>
<tr><td>PL_I</td><td>FMM_I</td><td>SS_I</td><td colspan="4"></td><td colspan="8"></td><td></td><td colspan="9"></td></tr>
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<tr><td>PL_N</td><td>FMM_N</td><td>SS_I</td><td colspan="4"></td><td colspan="8"></td><td></td><td colspan="9"></td></tr>
<tr><td></td><td></td><td>|</td><td colspan="4"></td><td colspan="8"></td><td></td><td colspan="9"></td></tr>
<tr><td></td><td></td><td>SS_N</td><td colspan="4"></td><td colspan="8"></td><td></td><td colspan="9"></td></tr>
<tr><td>PL_2</td><td>FMM_I</td><td>SS_I</td><td colspan="4"></td><td colspan="8"></td><td></td><td colspan="9"></td></tr>
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*CF = CUBIC FEET, AUM = ANIMAL UNIT MONTHS, AF = ACRE FEET, RVD = RECREATION VISITOR—DAYS, LB = POUNDS

Figure 2—FEES output display.

Literature Cited

1. Schweitzer, Dennis L.; Anderson, Ernest V.; Mills, Thomas J. Economic efficiency of fire management programs at six National Forests. Res. Pap. PSW-157. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982. 29 p.

2. U.S. Congress, U.S. Senate Appropriations Committee. Report 95-1063 on H.R. 12932. Appropriations bill for Department of Interior and related agencies, 1979. Washington, DC. 1978.

3. U.S. Department of Agriculture, Forest Service. Fire management analysis and planning handbook (draft) FSH 5109.19. Washington, DC: U.S. Department of Agriculture, Forest Service. 1981. 214 p. ■

Seasons and Frequencies of Burning

Forage studies reveal that May seasonal silvicultural burnings benefit the early growth of longleaf pine seedlings more than March burns. Now results are available from a study comparing March and May fires to determine if May burning also benefits young slash pines.

The study compared March and May prescribed fires initiated during 1972 in a 4-year-old slash pine plantation in southwest Louisiana. The annual March burn resulted in the least amount of pine height and diameter growth, accompanied by higher herbage yield. May burning was not significantly higher in survival and growth of young planted slash pines than March burning. While May burning benefits early initiation of height growth on longleaf pines, no advantage was found in the study for its use in young slash pine plantations.

For more details, request "Comparison of Seasons and Frequencies of Burning in a Young Slash Pine Plantation," Res. Pap. SO-185, from the Forest Service, Southern Forest Experiment Station, T-10210 U.S. Postal Services Building, 701 Loyola Avenue, New Orleans, LA 70113. ■

Escaped Fire Study

About 5 percent of all wildland fires in the United States escape initial suppression efforts and become project fires. These escaped fires account for roughly 95 percent of all wildfire-related costs and damages.

Current U.S. Department of Agriculture, Forest Service policy requires that suppression action on individual escaped wildfires be based on a formal analysis of alternative strategies—the Escaped Fire Situation Analysis. A 12-page report describes an initial study to determine the basic structure of escaped fire strategy decisions in terms of reasonable alternatives, appropriate decision criteria, and critical information uncertainties.

Study results suggest that decision analysis methods can provide a consistent and logical framework to evaluate alternative suppression strategies on escaped wildfires. The report also discusses the approaches to an escaped fire situation on the Wallowa-Whitman National Forest. A copy of the report, "The Escaped Fire Situation: A Decision Analysis Approach," Res. Pap. RM-244, can be obtained from Publications Distribution, Rocky Mountain Station, 3285 E. Mulberry, Fort Collins, CO 80524. ■

FIRESCOPE Multi-Agency Decisionmaking Process

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The cooperating agencies of the Firefighting Resources of Southern California Organized for Potential Emergencies (FIRESCOPE) have developed a decisionmaking system to coordinate the development and implementation of policy and procedures for over 250 Federal, State, county, and local fire service organizations.

FIRESCOPE was set up under Congressional mandate by the U.S. Department of Agriculture, Forest Service after the disastrous fires in California in 1970. To date, FIRESCOPE activities have concentrated on designing and testing systems for the day-to-day coordination and on-site management of emergency resources. Decisionmaking groups have also been identified. But fire service input and consensus on specific system requirements have remained elusive during the design effort. Expectations were not totally met relating to the role of individual agencies in defining system performance standards and requirements, and how anticipated differences will be resolved in reaching a consensus position (*1*). Activities have now shifted from system development to implementation. The Pacific Southwest Region of the Forest Service has worked with six California agencies to develop the decisionmaking system. The California Department of Forestry, Los Angeles City and County Fire Department, Ventura and Santa Barbara County Fire Departments, and the California Office of Emergency Services (representing all the remaining fire services in the FIRESCOPE region) are involved in the effort (fig. 1).

Figure 1—*The FIRESCOPE region involves the area generally south of the Tehachapi Mountains in Southern California.*

The Purpose and Process

The purpose of the decisionmaking concept was to create a "quasi" organization capable of: developing ownership in the program; proposing realistic systems and procedures; and functioning effectively with or without the program manager, his staff, and contractor support (*2*). To accomplish this the process was designed with the following components (fig. 2):

- A command level, or board of directors, responsible for making final decisions.
- An operations team to process information and formulate policy and action plans for the command level.
- Groups of staff people and technical specialists to perform the necessary preliminary work and to carry out the decisions processed at the two upper levels.
- An executive manager or program manager to monitor the decision process and disseminate information about decisions and assign tasks. (This person might also provide liaison with contractors as necessary.)

The board of directors is made up of the top administrators from the represented agencies and acts as the ultimate authority in the decisionmaking structure. The operations team consists of the operations chiefs from the involved agencies. The primary staff-level group, or task force, is supplemented when necessary by specialists who provide recommendations on specific matters. Task force members require comprehensive on-the-ground general knowledge and experience; specialists, on the other hand, are experts in their particular field such as training, mapping, communications, and the like.

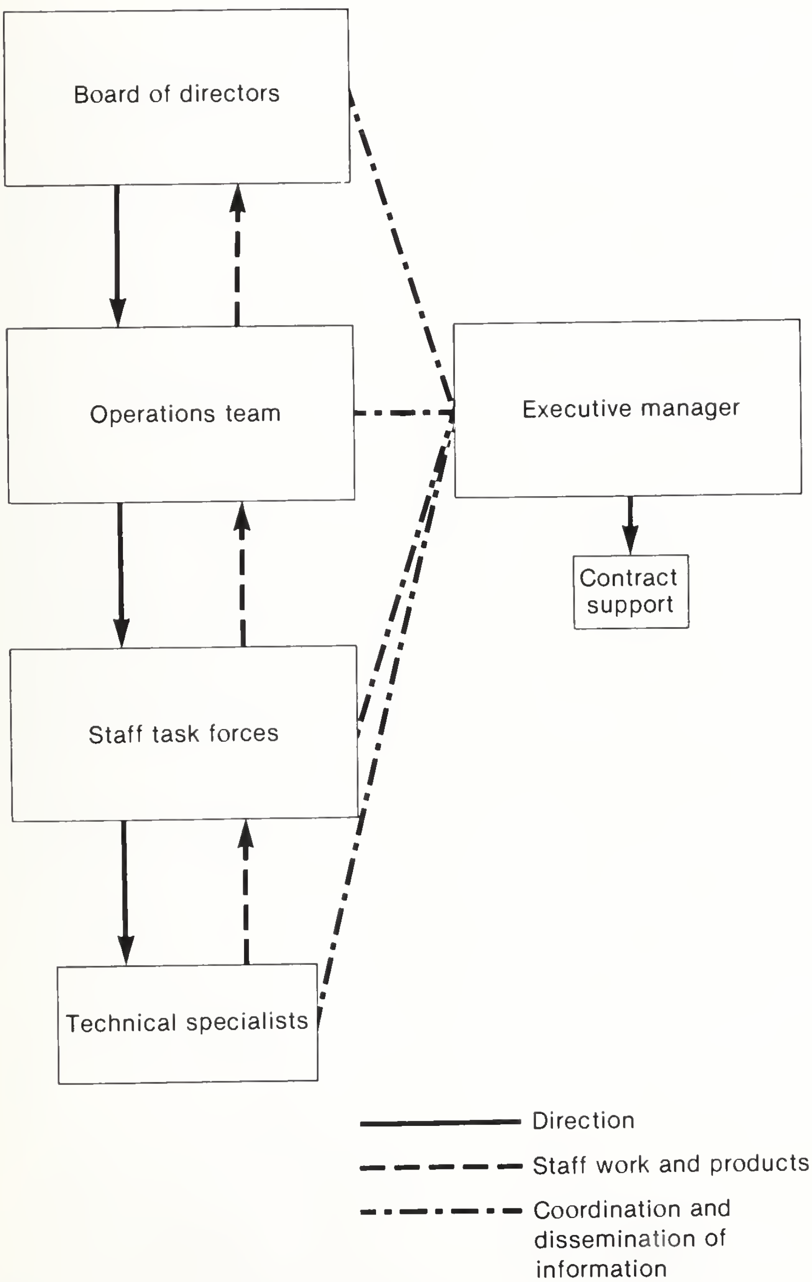

Figure 2—*FIRESCOPE decisionmaking process.*

The executive manager function is performed by the FIRESCOPE program manager or the manager's staff. The manager facilitates the decisionmaking process by providing the drive and overall direction for the decision process. This requires: a knowledge of where the decision process should be heading; the ability to be innovative; patience and flexibility; a knowledge of organizational and informational theories; a high tolerance for ambiguity; freedom, as much as possible, from the influence of any single agency; and a commitment to push, pull, and lead when necessary to keep the process moving.

The program manager or the manager's staff coordinate the process by sitting in on meetings at all levels. They provide a focal point for information flow, clarification of the mission, and liaison with contractors. To promote interaction and coordination, at least one member from the task force is assigned to each of the specialist groups. The chairperson of the task force attends the operations team meetings and the chairperson of the operations team attends the board of directors meetings.

Problem Solving

Most field level problems are identified by the task force, other specialists assigned by the participating agencies, or the program

manager. Once a problem has been identified, it must be completely defined by the group perceiving the problem, or others assigned by the program manager, the task force, the operations team, or the board of directors. For instance, if there is difficulty in radio communications, the executive manager, task force, or operations team will assign the communications specialist group to investigate the situation. These investigators will determine the specific problems, develop solutions, and report their findings to the task force for review. The task force will select an appropriate decision, make a recommendation to the operations team, or return the problem to the investigators for further study.

Approval of group findings before recommended actions are implemented can be accomplished at different levels of the decisionmaking process. For example, if the radio communication problem is related to differences in terminology, procedures, or field actions, the decision is made at the task force level. If the solution is a transition to new hardware and only involves operational expenditures with overall budget commitments, the decision will be made at the operations team level. If it requires a policy decision on sharing frequencies between agencies, the decision is made by the board of directors. Also, agency budgets and long-range implementation plans require approval by the board of directors. Final decisions are forwarded by the approving group for publication and implementation by affected agencies.

Examples of Success

The decisionmaking process has increased the effectiveness of southern California fire services by implementing several FIRESCOPE products. Some of the major decisions made by the FIRESCOPE decisionmaking process include:

- The use of a common, all-risk [1] incident management organization.
- The use of commonly understood terminology.
- The adoption of a uniform mapping system with a coordinated maintenance process.
- An agreement to share radio frequencies.
- A Multi-Agency Coordination System (MACS) allowing the sharing of agency personnel and equipment that uses a centralized computer to transmit and receive agency forces and incident status information.
- The development and coordination of multi-agency training.

[1] "All-risk" incidents result from any type of risk source, including wildland and urban fires, earthquakes, aircraft accidents, floods, and hazardous materials spills.

Conclusion

The willingness of the cooperating agencies to work collectively to accomplish common goals is one reason the decisionmaking system has been successful. The system itself offers many benefits to users and could be adapted to other uses:

- Decisions are implemented once consensus is reached, based upon each agency's needs, commitments, and abilities.
- Participation in the decisionmaking process gives all agencies a voice in future implementation while maintaining their agency's autonomy.
- Sound, viable decisions are made because all levels of the participating agencies, from the field to the executive level, are involved.
- Commitment to implementation of a final common product is achieved because all levels of each agency have had a part in developing and agreeing upon the product. In addition, the development process allows for a series of trials before implementation decisions are made.
- Agreements on commonality (in terminology, training, frequency sharing, organizational structures, procedures, and the like) greatly enhance interagency communications and effectiveness.

- Cooperating through the decisionmaking system insures consistent feedback and correction of errors.

The formal decisionmaking process was not a part of the original research design. However, because of its attributes, it is included in the major FIRESCOPE technologies now being disseminated nationally by the Forest Service through FIRETIP (Firefighting Technologies Implementation Project). Additional information concerning the decision process can be acquired from Marv Newell, USDA Forest Service-Cooperative Fire Protection, Boise Interagency Fire Center, Boise, ID 83705.

Literature Cited

1. Chase, Richard A. FIRESCOPE: A new concept in multi-agency fire suppression coordination. Gen. Tech. Rep. PSW-40. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1980. 17 p.
2. Irwin, Robert L. FIRESCOPE. Emergency Management Newsletter. January 4, 1982:2-3. ■

State Fire Plan

North Dakota has just prepared a statewide plan to help stop rural fires from laying thousands of acres to waste.

The plan defines which agencies will be involved in rural firefighting, at what stage they will contribute manpower and equipment, and where key personnel can be reached. It also lists restrictions that the Governor can invoke to prevent fires during periods of low, moderate, and high fire danger.

The State of North Dakota prepared the plan to prevent a repeat of a 1977 blaze that leveled thousands of rural acres before it was brought under control. At that time the State had no systematic approach to fighting rural fires that spread through several jurisdictions.

The plan coordinates activities of local fire departments, State and Federal forest services, State and Federal disaster services, the U.S. Department of Interior, Fish and Wildlife Service, and the North Dakota State Park and Recreation Service.

Under the plan, local fire departments respond initially to most wildland fires and contact the State's Disaster Emergency Service if they cannot bring them under control. The Service uses the statewide plan to systematically call up additional units from various firefighting agencies.

Although major fires probably will occur only once every 5 years, officials will review and update the plan annually.

For additional information contact Glenn Roloff, USDA Forest Service, Custer National Forest, 1824 North 11th St., Bismark, ND 58501, (701) 255-4011, ext. 443, or Dr. Robert Johnson, State Forester, Horticulture Building, North Dakota State University, P.O. Box 5658, Fargo, ND 58105, (701) 237-8174. ■

Analyzing the Economic Efficiency of Fire Protection

H. Ames Harrison

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Most of us have been experiencing the trials of the shrinking budget. In fact, no government agency—Federal, State, or local—has been exempt from increasing costs, tighter budgets, and closer accountability.

One of the areas affected by the budget crunch is wildland fire protection. In response to questions about the efficiency of funds being allocated for wildland fire protection, the U.S. Department of Agriculture Forest Service has developed a method of analyzing the efficiency of wildfire protection.

The analysis evaluates fire effects based on a "probability profile" of fires by frequency and intensity. The availability of historical records of fires and weather by wildfire area is essential to the analysis process. Uniform procedures have been designed to measure **net fire effects** and **costs.** The most efficient operation is the **lowest sum of the presuppression and suppression costs** plus the **resource value losses (or benefits)** on the unit being analyzed (see illustration). In this process, options such as fuels, detection, and prevention may be tested and their effects analyzed.

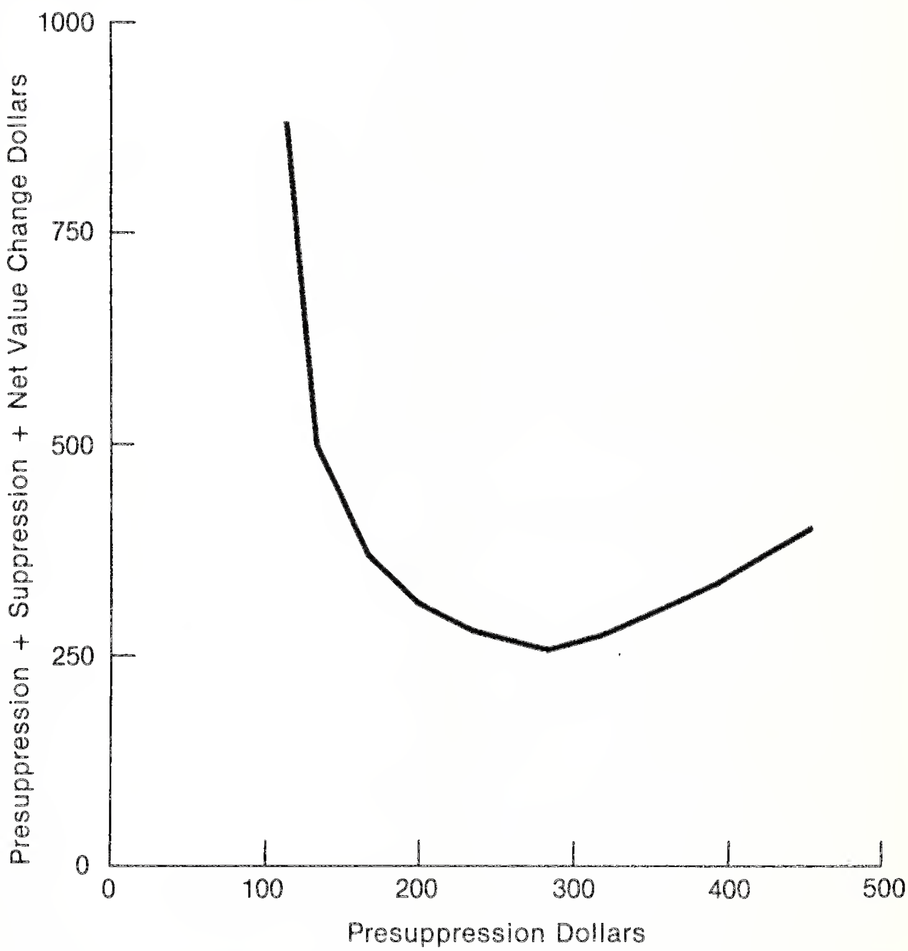

Illustration of the C + NVC Concept. *The lowest point on this curve is the most cost-efficient operation. The curve represents the sum of protection costs plus net resource value change.*

The fully operational process permits testing of management options obtained by varying the program mix and funding levels. Varying program mix means varying the presuppression forces (initial attack, prevention, detection, or fuels) to simulate specific programs. The manager will then be able to choose from an array of options the ones that are most cost efficient and that best fit the management area in terms of political or funding situations.

Experience using this analysis system on selected National forests led the Forest Service, in cooperation with the National Association of State Foresters, to adapt the process for use in the Forest Service's cooperative fire protection

program.

Use of the analysis is not limited to national organizations; it is practical for use by many State and local fire protection organizations as well. Information from the analyses can and has been used to support budget requests. It is also valuable input in resource planning.

In 1981 and 1982 a joint team of Forest Service and State forestry analysts analyzed the work of 39 organizational units representing the 877 million acres of non-Federal wildlands. The analysts concluded that most organizations can improve efficiency and reduce suppression costs and resource losses through program adjustments. In many cases, these program adjustments result in little, if any, budget increase. In some instances decreases in budget are appropriate if the most cost-efficient levels of operation are to be obtained.

The Forest Service and the National Association of State Foresters are moving ahead with program adjustments that will tie the analysis process and results into the cooperative fire protection staff of the Forest Service and finance fire protection to meet the Nation's need.

For more information, contact H. Ames Harrison, Cooperative Fire Protection Staff, USDA Forest Service, P.O. Box 2417, Washington, DC 20013. ■

Jeep-Mounted Fireline Plow Unit

Richard J. Barney and Jack W. Peters

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Most firefighting organizations have limited budgets for equipment. As a result, many are innovative in building equipment to meet both their firefighting needs and budget constraints. Throughout the years, the Montana Department of State Lands has been compelled to use and modify a large array of military equipment to meet its operational needs. One example of its innovative use of used equipment is a fireline plow unit that combines farming equipment and a conventional Jeep.

Plow Description

The firefighting plow unit is a single-bottom disk plow attached to a Jeep, obtained through the U.S. Department of Agriculture, Forest Service, Federal Excess Personal Property program. Other new or used four-wheel-drive vehicles can be adapted, including anything from surplus "bomb carriers" to modern four-wheel-drive vehicles or tractors. The plow is attached to the Jeep's pintle hook and raised and lowered by a hydraulic valve control powered by an electrical motor on a hydraulic pump system. The design is simple (fig. 1).

The plow disk is 24 inches in diameter. The hydraulic arm is a 24-inch cylinder powered by a 24-volt electrical pump system. On each side of the Jeep pintle hook, stabilizing hooks have been mounted to minimize side movement of the plow unit.

Figure 1—*The Montana Jeep fireline plow unit.*

Operating the Plow

The plow is operated simply by lowering the unit to clear fireline where needed. Figure 2 shows the plow unit making fireline in a sagebrush area. Like most plow units, this unit cannot be used in areas that are extremely rocky, have a large number of downed logs, or have very rough ground. There are many situations, however, that allow its application, such as open timber stands or brush and grasslands. The fireline is about 1-1/2 feet in width. If the plow unit is operated at the right speed for existing conditions, the material removed will turn over adjacent to the line, making an effective line of 3 feet or more in width.

To achieve the best results the equipment needs a good operator. An experienced person can

Figure 2—*Plow unit in operation in a sagebrush area.*

improve productivity and extend the operational range of conditions. Use of traction-type tires will also enhance operational capabilities.

The Plow's Performance

Several tests of the plow's performance were made on terrain ranging from 0 to 20 percent slope. Fireline was constructed going both uphill and downhill. As expected, ground and fuel conditions were important. Vegetative cover encountered ranged from heavy sagebrush-grass to moderately open second-growth pine and Douglas-fir areas with limited downed material. Soil types that were extremely rocky would not allow use of the disk. Depending upon site conditions, both low- and high-range four-wheel-drives were used. Fireline production rates varied from 152 to 397 feet per minute (138 to 361 chains per hour). Based on all tests, the average rate is about 300 feet per minute (272 chains per hour). Under sustained operational fire action, this average might drop as much as 50 percent. Ultimately, the operator and field conditions will determine production.

This unit, like any tool for fire suppression, does not meet all needs; however, it is useful. Considering the production rate, it can replace sizable crews in certain conditions. Based on field experience, the relatively small cost invested in this equipment has been recovered many times over. In fact, crew costs saved on one fire will pay for the unit.

Specifications and Fabrication

The basic unit is simple. The major components are: one disk plow; one plow arm; one hydraulic cylinder; one hydraulic pump; one electric motor; and one hydraulic control valve. A competent mechanic with welding capabilities can make such a unit from new materials for about $900. By using excess military property and scrounging from old farm and ranch implement yards, costs can be reduced considerably. Individuals may incorporate variations and modifications. Two useful modifications, for example, might be a brush screen in front of the Jeep or a good roll bar. However, experience dictates keeping it simple.

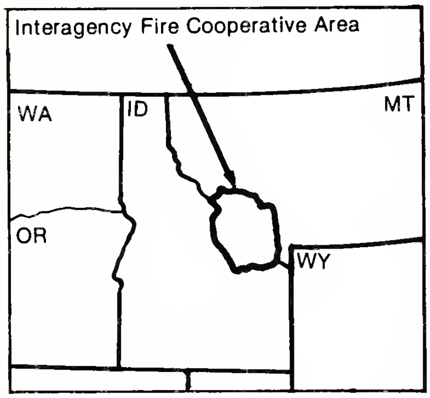
The jeep-mounted plow unit has another advantage. The unit can be constructed for easy mounting and dismounting so the jeep can be used for other tasks in the off-season.

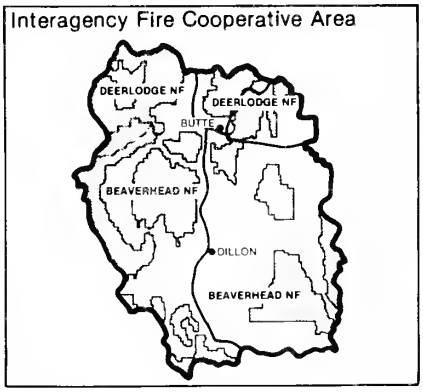
For additional information, contact Jack W. Peters. ■

Southwestern Montana Interagency Fire Cooperation

Ralph Stodden

Forest Dispatcher (Retired), USDA Forest Service, Deerlodge National Forest, Butte, Mont.





In June 1979, the Butte District, U.S. Department of Interior, Bureau of Land Management (BLM), and the Deerlodge and Beaverhead National Forests, U.S. Department of Agriculture, Forest Service (FS), entered an interagency agreement for fire protection of Federal lands in southwestern Montana. The objective of the agreement is to provide a more coordinated and economical aerial detection, fire dispatch, and initial attack system for approximately 5 million acres of land.

This agreement has enabled the BLM and the FS to handle a fire load during the 1981 season that would have been very difficult for any one of the three units to contain separately. The combined initial attack capabilities kept many fires from getting to project size. In fact, during the 1981 fire season action was taken on a total of 104 fires between the three units. Four of these were project-size fires ranging in area from 2,000 to 6,600 acres.

How the Agreement Works

To coordinate efforts between the three units, the operational procedures are written in an interagency operating plan for fire suppression and updated annually. The plan calls for an interagency coordination center, which is located at the BLM complex in Butte, Mont.

The coordination center activities are supervised by the Deerlodge National Forest dispatcher, who in turn, advises and informs the fire staff of the three units on coordination center activities. The center is responsible for gathering weather data from weather stations and entering it into the AFFIRMS (Administrative and Forest Fire Information and Management System) program, which transmits daily weather information and indexes to ranger districts and resource areas.

Daily cumulative fire reports are sent to the FS regional office and to the BLM State office. The coordination center handles requests for firefighters and equipment from ranger districts and resource areas as well as requests from the FS regional office and the BLM State office.

A fire cache is maintained in the BLM warehouse adjacent to the coordination center. The cache consists of enough handtools, safety equipment, and rations to equip 50 to 75 firefighters. Additional equipment and supplies are ordered from the Northern Region Fire Cache at Missoula, Mont.

Air detection is accomplished with two contract aircraft—one based in Butte and one based in Dillon—60 miles south of Butte. One flight pattern is flown out of Butte and one is flown out of Dillon. Air observers are furnished by BLM and FS.

BLM operates an electronic Automatic Lightning Detection System (ALDS) (see Fire Management Notes 42(4):3) that covers this interagency cooperative area. The Butte dispatch office uses the ALDS to plan lightning-detection flights, crew deployment, and similar tasks.

Radio communications has been quite difficult to coordinate because the three units use different frequencies and great distances are

involved. However, after 4 years of operation, this problem is almost solved. Aircraft are equipped with 9600 channel FM radios, new repeaters have been set up, and multichannel radios have been installed in mobile units. Some portable units are also available.

Teletype communications occur through an interagency fire teletype network extending throughout north Idaho and Montana. This teletype network will be replaced by the FS computerized Forest Level Information Processing System (FLIPS) in 1984.

Thirty-three people are available for initial attack for fire suppression, and by using the "closest crew" concept on initial attack, coverage has been good. Initial attack time has also improved. Location of crews is reported daily to the coordination center. The coordination center, in turn, posts location of crews on a map and notifies all ranger districts and resource areas of crew locations daily. Air tankers, smokejumpers, and other shared resources that may be needed are ordered through the Northern Region Fire coordinator.

In addition to improving suppression capability, the interagency agreement has had other benefits during these times of limited funds. It has eliminated a lot of duplication of effort and positions. For example, joint training sessions are held for firecrews, giving them the opportunity of working together. Two air patrols flown by two air observers has eliminated the need for both agencies to fly air patrols and finance four air-observer positions. Initial attack capabilities have greatly improved using the "closest crew" concept and, at the same time, makes fire suppression more cost effective.

In September 1982, the U.S. Department of Interior, Bureau of Reclamation, joined the interagency group. The interagency agreement will accept requests for inclusion from other wildland fire suppression organizations in the area. ■

Decision Analysis of Prescribed Burning [1]

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Prescribed burning has become an important management tool on the forests and rangelands of North America. Prescribed fire is used to reduce fuel hazard, as a silvicultural tool, to improve range condition and production, to improve wildlife habitat, to maintain vegetation types, and to sanitize forest stands (*17*). Much of the popularity of prescribed burning comes from its ability to help meet a wide range of management objectives efficiently. However, along with its increased use, prescribed fire degrades air quality and poses risks to property, resources, and human safety.

Resource managers must integrate various kinds and levels of information for planning and using prescribed fire. Decisionmaking is complicated by the uncertainty inherent in key decision variables. Managers require a logical, analytical decision framework that jointly considers the important variables (and their uncertainties) related to the decision criteria of effectiveness, safety, economic efficiency, and environmental quality.

These variables include: fire behavior; risk to public resources and private property; operational costs; costs of alternative management practices; wildfire hazard; effects of fire on resource outputs; and environmental, social, and political effects.

Decision analysis techniques (*3*) enable the manager to incorporate uncertainties in the decisionmaking process. The applicability of decision analysis for investigating wildland fire management problems has become increasingly evident during the past decade (*9*). Decision analysis has been used to plan fire prevention activities (*12*), to evaluate alternative fire protection program strategies (*13*), to allocate fire suppression resources, to appraise fire hazard from wildland fuels (*7*, *8*, *14*), and to determine the economic value of improved fuels and fire behavior information (*1*). Other research studies have applied decision analysis in evaluating the effectiveness of weather forecasts in prescribed fire decisionmaking (*6*), and in evaluating alternative suppression strategies on escaped wildfires (*15*).

Most of the examples of decision analysis in fire management have resulted from research. However, the techniques are easy to implement and could be applied profitably in operational decisionmaking.

This paper describes two generalized decision models that partially characterize decision processes for the evaluation and execution of prescribed fires. Although the two models do not incorporate all the factors managers must consider in planning for prescribed burns, they provide a starting point for developing more complete decision models. A hypothetical burn is used to demonstrate the application of these models.

Prescribed Burning Decision Models

Three distinct, but related, sequential decision processes are involved in planning fire use (fig. 1): evaluating the use of prescribed fire (fig. 2); the prescribed fire planning process (made in advance); and the prescribed fire execution decision (fig. 3). The decision process must be made consistent with organizational goals and objectives and meet all objectives and constraints as economically as possible.

Prescribed Fire Evaluation Process. The use of prescribed fire, whether ignitions are planned or unplanned, must be evaluated against alternative management strategies in terms of management goals and objectives, safety, physical and biological constraints, economic efficiency, and sociopolitical factors. Ultimately, the management strategy selected should maximize dollar value and net resource value change, while balancing nonmonetary considerations, such as risk to people and air quality. This decision process is closely related to the prescribed fire planning process.

[1] Paper presented at the Seventh Conference on Fire and Forest Meteorology, April 25-29, 1983, Colorado State University, Fort Collins, Colo.

Organizational goals and objectives → Prescribed fire evaluation process → Prescribed fire planning process → Prescribed fire execution decision

Figure 1—*Sequential decision process in planning the use of prescribed fire.*

A conceptual model of the elements involved helps in evaluating the use of prescribed fire (fig. 2). Management objectives determine the burning prescription. The prescription and environmental features determine the specific firing technique that will be used, which, in turn, controls the ultimate prescribed fire behavior. Fire behavior influences the many outcomes of the prescribed burn and the net value of the operation. The evaluation process helps to assure that the prescribed fire plan will be consistent with overall objectives.

Prescribed Fire Planning Process. The prescribed fire planning process develops logically from the prescribed fire evaluation process. Many of the planning considerations will have been included in the evaluation process. The prescribed fire plan is a formal, detailed description of the objectives, constraints, prescription, techniques, and logistics for carrying out the burn. Details of preparing burning plans are discussed by Fischer (*4*), Martin and Dell (*10*), Mobley and others (*11*), and Southwest Interagency Fire Council (*16*).

Prescribed Fire Execution Decision. After a prescribed fire has been planned, a series of decisions must be made before ignition. These decisions concern whether to proceed with the burn as planned, to modify the plan, or to cancel or postpone the burn (fig. 3). The decisions depend strongly on weather forecasts, actual weather conditions, weather persistence, the magnitude of the burning operation, and the ability to mobilize sufficient resources (people and equipment) for the burn. It is important that the decisions be consistent with broader policies, goals, and objectives, and with assumptions and objectives of the prescribed fire plan.

The use of a formal process could facilitate the short-term planning for resource requirements and give early indication of the need to modify the burning plan. It could improve efficiency by making best use of resources and by reducing the number of "false starts" on prescribed burns.

Decision Analysis of Prescribed Burning: An Example

The following illustrates an application of decision analysis in planning and executing a hypothetical prescribed fire. In this example, a prescribed fire has been recommended to reduce hazardous fuel accumulations in a 200-acre, thinned ponderosa pine stand. The proposed burn will also enhance the timber, range, and wildlife resource values. The burning prescription specifies mid-flame windspeeds of 1 to 5 miles per hour; 10-hour timelag fuel moisture of 10 to 20 percent; and relative humidity of 20 to 60 percent. This prescription will result in flame lengths from 1 to 4 feet with a 2- to 3-foot flame length being preferred. All 200 acres will be burned in 1 day, if the burning conditions remain within the prescription. The estimated cost of planning and executing the burn is $23 per acre. Of this total, $21.25 is the cost of conducting the burning operation. The additional $1.75 covers costs of planning and of mobilizing resources. Possible

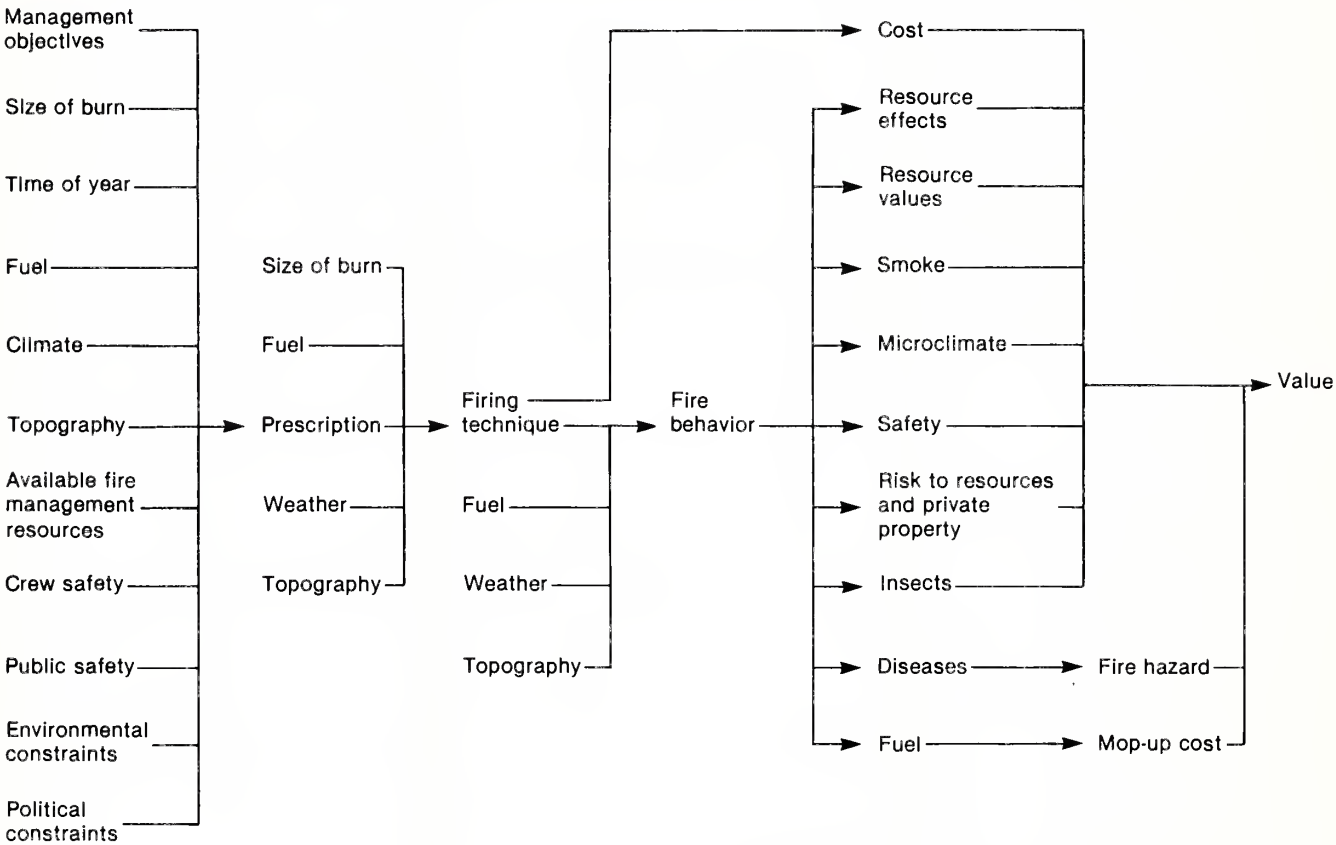

Figure 2—*Elements involved in evaluating the use of prescribed fire.*

costs because of false starts are not considered in this analysis, but they are considered in the subsequent analysis of the execution decision.

Events that can occur during the burning operation must be incorporated in the decision process for evaluating the prescribed burn. Possible events include:

- The weather and fuel conditions for burning may be acceptable (near lower or upper limits of the prescription) or preferred.
- Given the fuel conditions, weather conditions, and the firing crew's ability to control it, the fire behavior may be preferred (2- to 3-foot flame lengths) or acceptable (1 to 2 feet, or 3 to 4 feet). The burn will be stopped if flames are outside the acceptable range.
- Given the fire behavior, the burn may remain under control or it may escape and require suppression action.

Information is needed concerning the costs, benefits, and probability of occurrence of each event to estimate the expected value of the proposed burn. For this example, the value changes from fire

effects on the various resources (table 1) were estimated on the basis of fire behavior and the timing and duration of the effects. For example, a burn characterized by severe fire behavior leading to excessive crown scorch would produce resource effects having a present value of $30 per acre, while an ideal burn without negative effects on timber would produce benefits of $48 per acre.

The cost of suppressing an escaped fire is assumed to be $500 per acre for the planned area. This cost derives from the assumption that an escaped fire will burn an additional 100 acres, and that the net suppression cost, plus resource value change, will be $1,000 per acre for the 100-acre wildfire. This gross assumption was made to simplify the example. In reality, escaped fire size, suppression cost, and resource value change would vary according to weather conditions and the escaped fire's behavior.

A decision tree for the economic evaluation of the proposed burn (fig. 4) shows the events that could occur when the burn is executed, the probabilities of the various events (in parentheses), and the values of the outcomes of those events (right-hand column). For example, high flames normally lead to a value of $30 per acre, but, if the burn escapes control, the value is −$470 per acre (because of the $500 suppression costs). Note that it was assumed the full benefits of the prescribed burn were realized even if the fire ultimately escaped control. Alternatively, it could have been assumed that the prescribed fire yields no benefits if the fire escapes; however, the results of the analysis would be only slightly different.

The event probabilities are determined by the season of year, local climate, abilities of the burning crew, availability of holding forces, and chance weather events. For example, climatological data from fire weather stations could be used to estimate probabilities of meeting prescription (*2*, *5*). The probabilities would be different for burns planned in the spring and fall.

The expected value of the burn is derived by multiplying the probabilities and outcome values along each branch of the decision tree, and then summing for all outcomes. The expected net value of burning is the difference between the expected value and the estimated cost of burning. For this example (fig. 4), the expected net value is $26.10 minus $23.00, or $3.10 per acre. A similar economic analysis should be completed for each management alternative, and the results compared in order to select the best alternative.

Note that, if the uncertainties in the events were ignored, the estimated value of this burn would be $48 minus $23, or $25 per acre. The lower expected value (or long-term average value) results from acknowledging the fact that unfavorable outcomes are indeed possible.

Each event in figure 4 has associated with it some degree of uncertainty, expressed as a probability. How might reducing this uncertainty affect the expected

Table 1—*Present value costs and benefits used for computing the expected value of the example burn.*[1]

Fire impact	Years of impact	Flame lengths		
		Acceptable, but low	Preferred	Acceptable, but high
		- - - - Dollars - - - -		
Fire hazard reduction	1-5	8.90	22.26	22.26
Timber	30	3.08	15.42	− 3.08
Wildlife	1-5	–	6.68	6.68
Range	1-10	4.06	4.06	4.06
Total (rounded)		16	48	30

[1] Dollar values are per-acre present values based on a 4 percent interest rate.

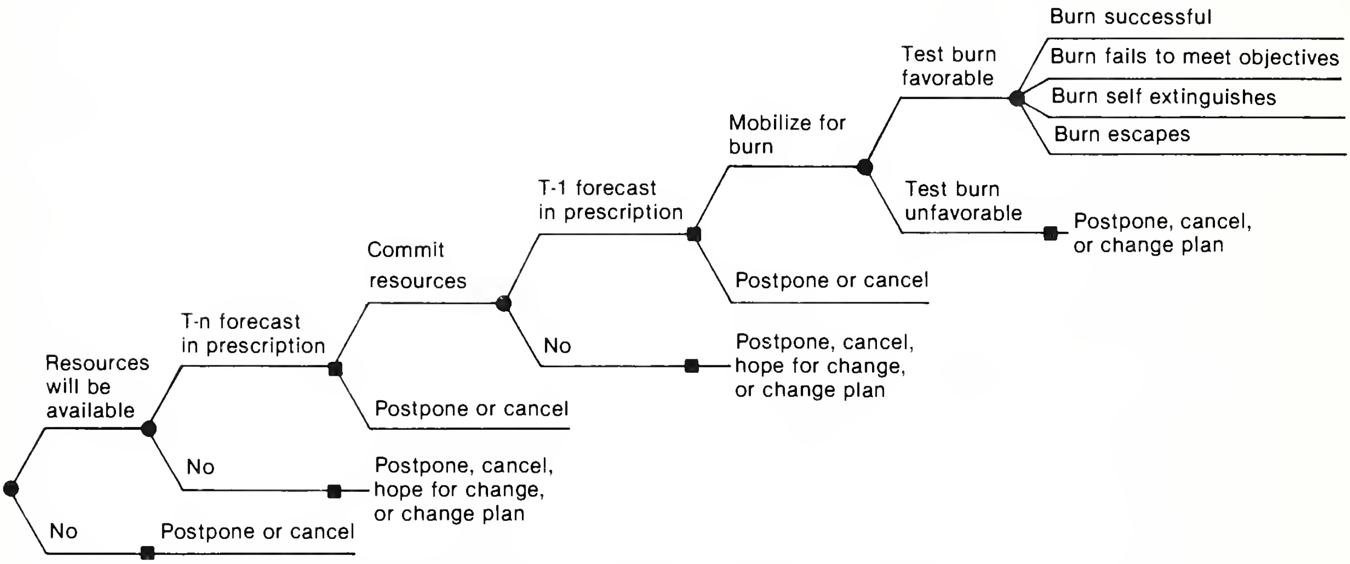

Figure 3—*Decisionmaking process in executing a prescribed fire. Circles are probability nodes; squares are decision nodes. T-n is the last day before burning to commit resources. T-1 is 1 day before the scheduled burn. They may be the same day.*

value of burning? As an example, suppose that the burning crew could better regulate the fire behavior to increase the probability of burning the area under optimal fire behavior. If the chances of achieving the preferred fire behavior were increased from 0.4 to 0.6 for acceptable weather conditions, and from 0.6 to 0.8 for preferred weather conditions, the result is an increase in the expected net value from $3.10 to $9.60 per acre. This gives an indication of the possible value of improved firing techniques or ignition methods.

Conversely, how might the expected value change if the probability of an escaped fire doubled? This could be the result of changes in the holding plan, or of stand conditions that favored the possibility of torching and spotting. The expected net value of burning under this higher risk of escape is −$5.80 per acre. This type of analysis could be used to determine whether additional costs for more holding forces are justified.

When the burning plan is completed, the decision to execute or to postpone the burn depends on the weather forecasts at critical times prior to the burn date, the level of uncertainty inherent in the forecasts, the expected value of the burn, and the estimated costs of postponing the burn. Events, probabilities, and outcomes that characterize the decision process for executing the example burn are shown in the decision tree in figure 5.

The cost of postponing the burn *n* days before the burn date includes weather forecast expenditures, computer analysis costs, and the cost of gathering information concerning the availability of resources for executing the planned burn. Note that the costs listed in figure 5 are total costs, not per-acre costs. Postponement of the burn 1 day before the burn date adds the costs of an additional weather forecast and of placing personnel and equipment on standby. The increased cost of canceling the burn based on an unfavorable test fire is attributable to the cost of having the personnel and equip-

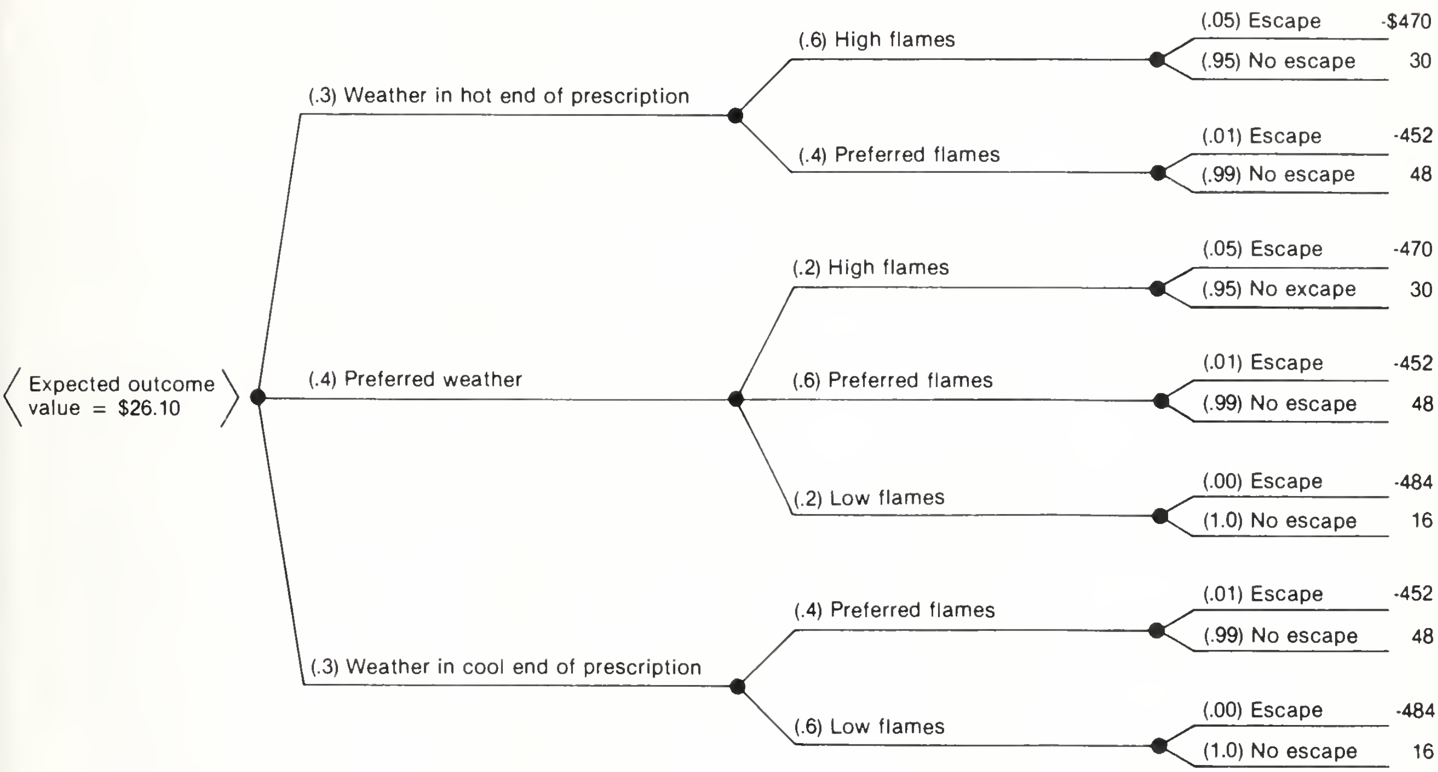

Figure 4—*Evaluating the cost of the example burn. The probabilities of the various events are in parentheses. The values of the outcomes are listed at the far right. The expected net value of the burn is $26.10 (the expected outcome value) minus $23.00 (the estimated burning cost) or $3.10 per acre.*

ment at the burn site.

The expected net value of burning is $620 as determined in the previous evaluation process ($3.10 per acre × 200 acres).

Figure 5 illustrates a situation for which weather forecasts carry a relatively low degree of uncertainty. For this situation, the expected value for executing the burn is $411.13 ($2.06 per acre). This lower expected value than that calculated in the evaluation model ($3.10 per acre) results from considering the possible negative impact of "false starts" in executing the burn.

A key aspect of the prescribed fire execution decision model is the uncertainty inherent in weather forecasting. For example, what would be the result of increased uncertainty in the weather forecast? If the forecast probability of being in prescription were reduced from 0.9 (as in fig. 5) to 0.5, the expected value of the burn would be reduced to −$8.75 (−$.04 per acre). In other words, that degree of uncertainty for meeting the prescription would lead to the decision not to proceed with the burn.

On the other hand, if there is a significant opportunity cost associated with postponing the burn, it may still be desirable to proceed. Early in the burning season, when postponing a burn causes only a minor delay, this may not be an

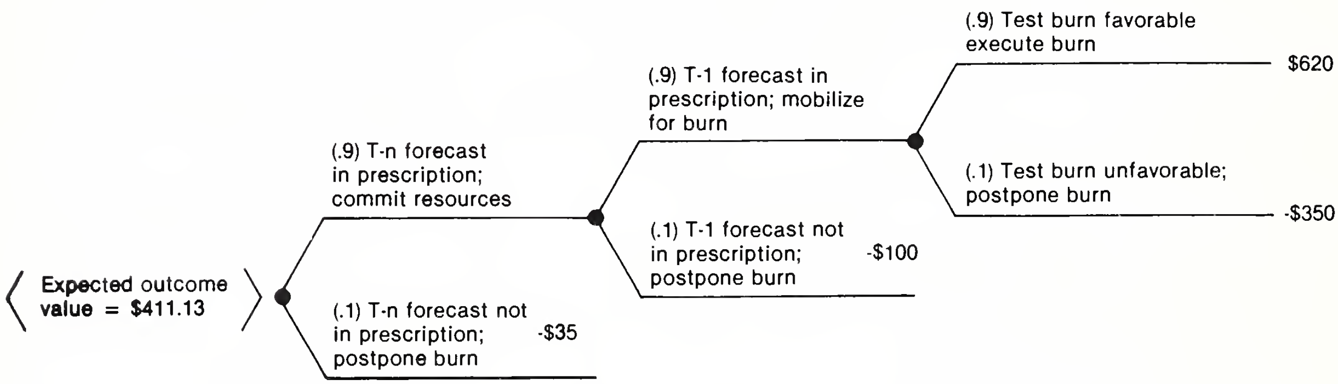

Figure 5—*Decision tree representing the prescribed fire execution decision for the example burn. The probabilities of the various events are in parentheses. The values of the outcomes are listed at the far right. This shortened version of figure 3 shows only the probability nodes.*

important consideration. Late in the season, however, postponement may result in a substantial delay in realizing some benefits, or may require increased fire protection costs. In such a situation, the opportunity costs could be of major importance. In the example used here, a $200 opportunity cost of postponement ($1.00 per acre) results in the decision to proceed with the burn even if there is only a 0.5 probability of meeting the prescription.

Conclusions

The example demonstrates how decision analysis can be used for evaluating and planning prescribed fires, and for analyzing decisions associated with execution of a planned burn. Decision analysis provides a means by which prescribed fire decisions can be structured to represent relationships among the decisions, information requirements and flows, and critical uncertainties.

The two decision models only partially represent the complexity involved in decisionmaking for planning prescribed fire. The models must be expanded and tested to make them operationally useful. Although they are incomplete, the models illustrate the importance of explicitly incorporating uncertainties in the prescribed fire decisionmaking process. Only by doing so is it possible to adequately reflect the possible consequences of prescribed burning. Decision analysis makes it possible to evaluate the importance of procedures for reducing uncertainties, and of improved procedures for conducting prescribed burns.

Literature Cited

1. Barrager, Stephen M.; Cohan, David; Roussopoulos, Peter J. The economic value of improved fuels and fire behavior information. Research Paper RM-239. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; 1982. 32 p.
2. Bradshaw, Larry S.; Fischer, William C. A computer system for scheduling fire use. General Technical Report INT-91. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station; 1981. 63 p.
3. Brown, Rex V.; Kahr, Andrew S.; Peterson, Cameron. Decision analysis: An overview. New York: Holt, Rinehart, and Winston; 1974. 86 p.
4. Fischer, William C. Planning and evaluating prescribed fires—a standard procedure. Gen. Tech. Rep. INT-43. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station; 1978. 19 p.
5. Furman, R. William. Using fire weather data in prescribed fire planning: Two computer programs. Gen. Tech. Rep. RM-63. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 11 p.
6. Furman, R. William. The effectiveness of weather forecasts in decision making: An example. Journal of Applied Meteorology 21:532-536; 1982.
7. Hirsch, Stanley N.; Meyer, Gary F.; Radloff, David L. Choosing an activity fuel treatment for southwest ponderosa pine. Gen. Tech. Rep. RM-67. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 15 p.
8. Hirsch, Stanley N.; Radloff, David L.; Schopfer, Walter C.; Wolfe, Marvin L.; Yancik, Richard F. The activity fuel appraisal process: Instructions and examples. Gen. Tech. Rep. RM-83. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; 1981. 46 p.
9. Martell, D. L. A review of operational research studies in forest fire management. Canadian Journal of Forest Research 12(2):119-140; 1982.
10. Martin, Robert E.; Dell, John D. Planning for prescribed burning in the inland northwest. Gen. Tech. Rep. PNW-76. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 67 p.
11. Mobley, Hugh E.; Jackson, Robert S.; Balmer, William E.; Ruziska, Wayne E.; Hough, Walter A. A guide for prescribed fire in southern forests. Atlanta, GA: USDA Forest Service, Southeastern Area; 1978. 40 p.
12. Nickey, B. B.; Chapman, C. B. Evaluating fire prevention effectiveness through a probability model. Fire Technology 15:291-306; 1978.
13. North, D. Warner; Offensend, Fred L.; Smart, Charles N. Planning wildfire protection for the Santa Monica Mountains: An economic analysis of alternatives. Fire Journal 69(1): 9 p.; 1975.
14. Radloff, David L.; Schopfer, Walter C.; Yancik, Richard F. Slash fire hazard analysis on the Siskiyou National Forest. Environmental Management 6(6):517-526; 1982.
15. Seaver, David A.; Roussopoulos, Peter J.; Freeling, Anthony N. S. The escaped fire situation: A decision analysis approach. Res. Pap. RM-244. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; 1983. 12 p.
16. Southwest Interagency Fire Council. Guide to prescribed fire in the southwest. Phoenix, AZ: Southwest Interagency Fire Council; 1968. 58 p.
17. Wright, Henry A.; Bailey, Arthur W. Fire ecology: United States and southern Canada. New York, NY: John Wiley and Sons; 1982. 501 p. ■

Recent Fire Publications

Alexander, M. E. Tables for determining spring drought code starting values in west-central and northern Canada. For. Manage. 19. Edmonton, AB: Environment Canada, Canadian Forestry Service, Northern Forest Research Centre; 1983. 8 p.

Anderson, Hal E. Predicting wind-driven wildland fire size and shape. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 26 p.

Andrews, Patricia L.; Rothermel, Richard C. Charts for interpreting wildland fire behavior characteristics. Gen. Tech. Rep. INT-131. Odgen, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 25 p.

Barrager, Stephen M.; Cohan, David; Roussopoulos, Peter J. The economic value of improved fuels and fire behavior information. Res. Pap. RM-239. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1982. 32 p.

Baumgartner, David C. Wildland fire management economics: A state of the art review and bibliography. Gen. Tech. Rep. NC-72. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 49 p.

Brown, James K.; Oberheu, Rich D.; Johnston Cameron M. Handbook for inventorying surface fuels and biomass in the interior west. Gen. Tech. Rep. INT-129. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 52 p.

Donoghue, Linda R. Classifying wildfire causes in the USDA Forest Service: Problems and alternatives. NC-280. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 7 p.

Donoghue, Linda R. The history and reliability of the USDA Forest Service wildfire report. Res. Pap. NC-226. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 15 p.

Federal Emergency Management Agency. Fire in the United States. FEMA-22. 2nd Edition. Washington, DC: Federal Emergency Management Agency; 1982. 62 p.

Fischer, William C.; McClelland, B. Riley. A cavity-nesting bird bibliography—including related titles on forest snags, fire, insects, disease, and decay. Gen. Tech. Rep. INT-140. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 79 p.

Forest Service Equipment Development Center. Lot acceptance and quality assurance procedures for long-term retardant, forest fire, aircraft or ground application. 5100-Fire. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Forest Service Equipment Development Center; 1982. 3 p.

Freeman, Duane R. Inventory and prediction of forest fuels. In: In-place resource inventories: Principles and practices. Proceedings of a national workshop; 1981 August 9-14; Orono, ME. Washington, DC: Society of American Foresters; 1981: 904-907.

Freeman, Duane R.; Loomis, Robert M.; Roussopoulos, Peter J. Handbook for predicting slash weight in the northeast. Gen. Tech. Rep. NC-75. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 23 p.

Green, Lisle R. Using goats to control brush regrowth on fuelbreaks. Gen. Tech. Rep. NC-59. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982. 12 p.

Greulich, Francis E.; O'Regan, William G. Optimum use of air tankers in initial attack: selection, basing, and transfer rules. Res. Pap. PSW-163. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982. 8 p.

Harrington, James B. A statistical study of area burned by wildfire in Canada. Can. For. 3(6):64; 1982.

Larson, Jeanne R.; and Duncan, Don A. Annual grassland response to fire retardant and wildfire. J. Range. Manag. 35(6):700-702; 1982.

Maller, Peter. Simulating conflagrations. Firehouse 8(3):72-74; 1983.

Perry, Donald G. Tackling the problems of wildland firefighting. West. Fire J. 35(2):43,44 & 63; 1983.

Steele, Robert W.; Barney, Richard J. Bulldozers in fire management: Current designs and uses. Res. Note INT-328. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 4 p.

Taylor, Mark. Wildfire in North Carolina. Fire and Wildfire 46(11):19-23; 1982.

U.S. Department of Agriculture, Forest Service. Consumer information guide: Chain saw safety. Washington, DC: U.S. Department of Agriculture, Forest Service; 1982. 12 p.

Van, Nao T., ed. Forest fire prevention and control. Proceedings of an international seminar organized by the timber committee for the United Nations Economic Commission for Europe; Warsaw, POLAND; 1981 May 20-22. Boston, MA: Martinus Nijhof and Dr. W. Junk, Publishers; 1982. 236 p.

Van Wagner, C. E. Annotated bibliography of forest fire research at the Petawawa Forest Experiment Station. Can. For. 3(6):65; 1982.

Viereck, L. A. The effects of fire in black spruce ecosystems of Alaska and northern Canada. In: The role of fire in northern circumpolar ecosystems. New York, NY: John Wiley and Sons, Ltd.; 1983: 201-220. ■

Water Handling Guide Available

The National Wildfire Coordinating Group (NWCG) has recently published a new Water Handling Equipment Guide, NFES stock no. 1275. The new guide is available at a cost of $1.36 each from: Boise Interagency Fire Center, 3905 Vista Avenue, Boise, ID 83705. USDI agencies and Forest Service units may also order through their regional fire cache at the same price.

The new, 100-page guide contains basic information on water handling equipment to assist field users in selecting proper equipment. It replaces the Forest Service water handling equipment guide. ■

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